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Paper:

Jenkins, A., Lindsay, S., Eslambolchilar, P., Thornton, I. & Tales, A. (2016). Administering Cognitive Tests Through Touch Screen Tablet Devices: Potential Issues. *Journal of Alzheimer's Disease*, 54(3), 1169-1182.
<http://dx.doi.org/10.3233/JAD-160545>

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Monitoring Cognitive Tests Through Screen Tablet Devices: Potential

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Technologies, such as tablet devices, open up new possibilities for health-related diagnosis, monitoring, and assessment for older adults and healthcare practitioners. Current evaluations of cognitive integrity typically occur within memory clinics, using pen and paper or computer-based tests. In the present study, we investigate the feasibility of transferring such tests to touch-based, mobile technology platforms from an older adult population. Factors that may include individual variability in technical familiarity and acceptance; various factors influencing test validity; response characteristics and thus validity *per se* of a given test. For the results of mobile technology-based tests to be valid and related to disease status rather than extraneous variables, it is imperative the validity of such tests is investigated in order to determine potential effects before the test is fully developed. Researchers have emphasized the importance of including the 'user' in the evaluation of such devices; thus we performed a focus group-based investigation of the processes involved in the administration and performance of a tablet-based version of a typical information processing speed (a multi-item localization task), to younger and older adults. We report that older adults regarded positively, indicating that using a tablet for the delivery of such tests is feasible, it is important to consider factors surrounding user expectations, performance feedback, and physical response requirements in order to inform further research into such applications.

Attention, cognition, focus groups, qualitative research, tablet computers

scale up for a large number of users and demand.

Mobile technology (mHealth) has been used to address different healthcare challenges to help people living with chronic conditions such as diabetes. Due to the 'connected' nature of mobile devices and the growing availability of broadband, the idea of 'information to support the management of' has extended beyond traditional medical settings. Mobile provides a platform for community-based health where users share experiences and information about a condition [4]. More advanced research includes the idea of using on-body sensors to monitor people's health and to transmit readings to their mobile device via wireless area networks [5, 6]. Data gathered through these means can be used for diagnosis and monitoring processes and the use of their use in physical conditions can also be applied to the management of chronic conditions [9]. However, although research has been done on various health-related apps by older adults to indicate what factors affect app use by this population [2, 8–10], there is a need for research investigating the use of mobile devices in assessing information or cognitive function in older adults. This is especially true for individuals living with cognitive impairment or dementia. Although it sounds simple, moving away from testing on PCs by older adults to tests for use with touch screen devices on this platform can introduce new challenges related to the technology per se and the human interface. Biases may, for example, potentially affect the accuracy, validity, and specificity of the test and the robustness of the test.

Attention-related function in older adulthood, in both research and clinical arenas, with disproportionate slowing and raised variability associated with mild cognitive impairment, Alzheimer's disease, and vascular dementia [13–16]. As RT speed and variability appear to be behavioral indicators of the integrity (at least in part) of white and grey matter [17] in older adulthood and neurodegenerative dementia processes such as Alzheimer's disease, such measures may be of use clinically.

Arguably, RT and IIV_{RT} testing appear particularly suited to delivery or presentation via a touch screen tablet as they tend to be cheaper and simpler to use than laptops or desktop computers and can have multiple advantages over computers for testing information processing in older adults [9, 18, 19]. However, it is also increasingly clear that factors unrelated to brain structure and function and a disease process can influence RT and IIV_{RT} and that it is vital to determine, investigate, and ameliorate such effects with respect to the touch screen tablet platform, in order to ensure test validity.

Evidence already reveals that there are a number of challenges to be aware of when digital technologies are used by older adults including physical issues such as decline in manual dexterity and eyesight and decreasing cognitive capabilities, frustration, the need for specific training, age, gender, dry finger skin, and age-related cognitive motor skills [2, 18–22], all factors likely to affect the performance of RT and IIV_{RT} tests using a touch screen platform and thus their clinical validity, usefulness, and robustness. Furthermore, RT research has revealed many participant and methodology-related factors capable of significantly affecting RT study outcome including: the test item, the environment, response requirements,

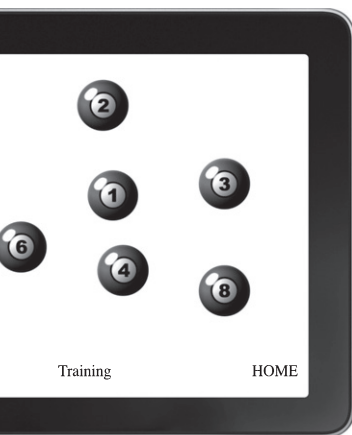


Figure 1. Screenshot of the iPad MILO task used in the current study.

perform sequences of actions [29, 30] (e.g., the Trail Making Task [31]) and cancellation tests [32] in requiring a sequence of responses to be identified in a specific order. A typical trial from the tablet implementation of the MILO task that was used in the current study would be to touch each item in sequence, from one to eight. Advantages of computer-based presentation over paper-and-pencil tasks include the ability to provide visual feedback for each item, rather than simply a verbal cue (e.g., [32]) and the ability to manipulate patterns of search organization. In addition to these, the MILO task makes it possible to manipulate the sequence type (e.g., forward, backward, or both) and sequence behavior (e.g., touching or remaining, sequence position or shuffling between responses).

use with this population [35–37]. For example, there are a number of challenges to be aware of when digital technologies are used by older adults including physical issues such as decline in manual dexterity and eyesight and decreasing cognitive capabilities, both potentially hindering interaction with mobile platforms, which are not adapted to their needs [18, 19, 22]. In the MILO task, the target object size and spacing were well within these suggested limits and responses could be self-paced. More specifically, when the iPad was placed on a table 50 cm in front of participants, each 1.9 cm item subtended approximately 2° visual angle, with gaps between items varying between 0.8° and 8° visual angle. To successfully complete a trial, participants were required to touch each object following the numeric sequence one to eight as quickly as possible, but there were no specific time limits, so participants could calibrate their responses taking into account any motor limitations.

When an item was touched, it vanished from the screen, so that the set size, and search difficulty was reduced with each response. Touching an item out of sequence (i.e., a mistake) resulted in the termination of the trial and visual feedback in the form of a schematic sad face. There was a two second inter-trial interval and no feedback on speed or accuracy was provided for correct trials. Each participant completed 10 training and up to 10 experimental trials and at the start of each trial the position of all target items was randomized within the constraints of a virtual grid that was programmed to ensure items did not overlap. As our goal was to explore factors related to presenting a RT task using a touch screen tablet format *per se*, we did not record actual RT performance as participants were allowed to comment upon any

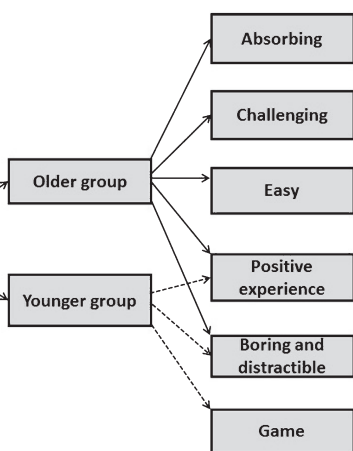
al-time feedback upon task acceptance. Furthermore, the researcher administering the test typically sits close to the participant, making the test; anecdotally this has been off-putting to the person taking the test. The researchers, but it may also be reassuring to participants, but it may also be reassuring to participants. Therefore also examined this factor in terms of test acceptability and performance. In a previous study [28], recruited eleven younger adults (18-30 years) and twelve older adults (65+ years) for a one and a half hour focus group. The participants were recruited via University block-lists, notices, and word of mouth. The participants were recruited via the Older People and Adult Development Network (OPAN) and the Older People Networks. Poor general health, cognitive limitations and participation in other research studies formed exclusion criteria. All members of the research team were present during the focus group and the other observing and taking notes. A semi-structured schedule was followed. The methodology is discussed in full in Jenkins et al. [28]. It is an iterative; there are of course limitations to this qualitative technique, which have been identified and addressed in order to ensure, that they did not introduce bias. For example, the knowledge, skills, and experience of the researcher conducting the focus group can have an unfair influence on the generation of information from the participants. In order to avoid such an impact, the researchers ensured there were two members of the research team present, one leading and the other observing and taking notes. A semi-structured schedule was followed but also encouraged expansion on areas. Qualitative analysis is rarely used in the field of computer science therefore

Table 1 Focus group schedule (iPad test experience)	
Focus group section	Questions and prompts
iPad test	-Has anyone used an iPad/similar device before?
feedback	-How would you describe your experiences of using the test?
questions	-Prompt – was it enjoyable or not? -How well did you think you have done? -What parts of the tests did you find challenging? -Prompt - was it too fast? Hard to pay attention to, etc.? -Was the iPad easy to use?

The focus groups were audio-recorded, and a member of the research team took notes. A semi-structured predetermined framework of open-ended questions was used to ensure all aspects relating to the topic area were explored (Table 1). The focus group recordings were transcribed verbatim, and all identifiable information was either removed or consistently anonymized. Thematic analysis was employed on the interview data, which was realist driven, inductive, and bottom-up [38]. Two members of the research team read and re-read the transcripts making initial comments and codes. The process was repeated twice more until individual codes were identified. Subsequently these were grouped into three major themes that emerged across both younger and older participant groups, namely ‘views of test experience’, ‘testing situation and materials’, and ‘test performance’.

RESULTS

A number of themes and sub-themes have been identified highlighting categories rather than preva-



Views of test experience.

-theme 'absorbing' which represents some of the older participants said about the iPad test experience. For

it quite absorbing myself because concentrate on what was in front of you to pin point what the next number say it occupied all my thoughts I to do it as quickly as I could, and as I could. I was totally absorbed numbers. Which is strange for me and does tend to wander and it didn't occasion".

-theme reflects the older participants' views that the test was a 'challenge', -theme that it was 'easy'. For

Positive experience (older): "[P]: it was quite enjoyable. [W]: and I think the more you did it the more you wanted to do it somehow".

Positive experience (younger): "[R]: fab, thank you. Did you enjoy doing the test? [A]: it makes me want one [iPad]. [P]: it was interesting but I wouldn't use the word 'enjoy' [laughter] I was just counting dots but it was a little more engaging than some can be. [S]: it made me wonder if they were dots or pool balls [laughter] I think it was nice that it changed on each trial. Like in a paper pencil version of a trail making there is only one set way of doing it and I like having the variation that it is new every time you do it, maybe it is more accurate that way".

The sub-theme 'boring and distractible' is also a shared view in opposition to the test being a positive experience. For instance:

Boring and distractible (older): "[R]: so how did you find the test? [G]: a bit boring I found it, sorry. Repetitively boring there was obviously a sequence for that. I said that to [researcher] I said 'is this um could you memorise these if you had a good memory and numerative memory?' The problem is going too fast and then thinking something more interesting may come up next time. It was the same numbers just in a different location. Yeah I found it boring towards the end. [R]: yes and that is perfectly fine, I want you to be as honest as you can. Thank you [G]".

Boring and distractible (younger): "[R]: ok, so would you say then something like that could be used on a regular basis or would you say no? [L]: I think it was boring"

I was thinking well what the purpose is, what it is going to be used as. It is something to do with cognitive, I wondered what well if it would be like a kind of positive feedback in because I made a mistake and the sad face and that was feedback how to get people to play it maybe maybe it would have like increased a score. That would make them don't know if I would play it regardless the sake of doing it as it is now just like tapping the numbers and that I am doing good. [A]: yeah you want to improve and beat your like progression or how well I am on different levels, like the next level 10 numbers".

Testing situation and materials

There are three sub-themes developing from both the older and younger groups. The first sub-theme reflects the views regarding the experience they had of the testing situation and materials:

Experience (older): "[R]: yes but she was getting scores, what's more important was the feedback from the tests. Did you find it useful to use? [A]: yeah. [G]: well I did use it very well but it was fine. [J]: I think it's the same as you; as soon as I started using it I was more accurate. And these were the only things I had in all the time [glasses], but it was broken so I had to use them back up. [R]: yeah ok so

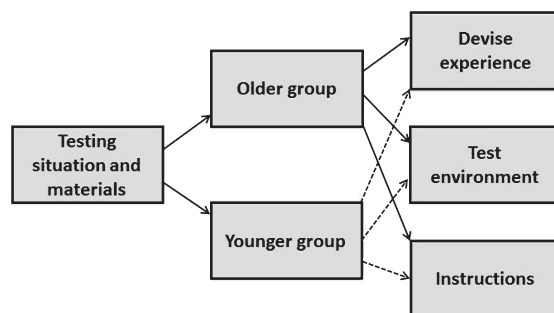


Fig. 3. Testing situation and materials.

or play the piano are quicker at that than people who are not? [R2]: at the moment we don't for that test but from what we know of other things we wouldn't be surprised if they were, absolutely. [A]: I think you're right though, it's like kids on mobile phones, they are so fast. Like when I text...well I am faster than I used to be but not as fast as they are. [J]: when using a keyboard I do try and type properly. My granddaughter goes so fast when typing but then has to go back to attend to her mistakes, where as I go slower but have less mistakes".

Device experience (younger): "[R]: ok, thank you. How about the positioning of the iPad? [L]: fine. [P]: I moved it. [R]: where did you move it to? [P]: I just moved it closer. The angle was a bit well I didn't move the angle. For me it would have been better flat but maybe because it was quite far into the table. [RB]: it would have been helpful to have one of those holders, what are they called? [P]: like a copy holder? [RB]: yeah, just to have it in front of you. I wonder what that would

conscious of that as well. [S]: yes
mind as well. [N]: I think it might
tly different if she had said 'right
do this. This is what you have got
and do it and I am going out of the
would have approached it slightly
tally".

ent (younger group): "[L]: yeah so
happy face could spur someone on
d faster but then other people will
py face and think 'oh no!'. [P]: it
pletely. [RB]: same [laughter]. I
er] was sat next to me and I didn't
e the faces. [R]: do you think it
de a difference if [researcher] was
? [RB]: yeah, I didn't want her to
well at that angle she couldn't have.
w that the unhappy face does mean

theme relating to testing situation
regarding the 'instructions' that were
participants to complete the iPad test. For

lder group): "[M]: yes I am with
quite interesting and I am not a
but I do use all my fingers on the
o I had all my right hand out. And
though ahhh maybe I could use
o but I didn't because I thought it
ing. I learned to look at the pattern
l, but I wondered if you ever con-
one of these clever gadgets that
n your glasses or on your head or
so that they can see where you are

would be different. So I don't know, again in terms
of the instructions of the set way of doing the task
maybe there has to be a certain distance from the
screen or uh I don't know, something that would
make sure it is standardised for everyone".

Test performance

This theme has six sub-themes, four of which are
shared between the two age groups, and one unique
to each (Fig. 4). The theme relates to how the par-
ticipants felt they performed at the iPad test. The
first sub-theme 'accuracy' is based only on the older
participants. For instance:

"[R]: so what did you think? Was it due to more
accuracy or speed? [N]: a combination of both I
think. [P]: yeah it is no good going fast if you're
going to get it all wrong is there. [J]: I was disap-
pointed with the number of mistakes I did make,
obviously trying to go too fast. [P]: I made one but
I think it was because I didn't press hard enough
on the screen. The face came up [showing sad
face]".

The second sub-theme is the 'use of hands' whilst
using the iPad. For instance:

Use of hands (older group): "[A]: the only prob-
lem I had with the touch screen is my nails. I
have this problem at home, and that's why I use
a [brand name] pen because I find you have to
develop a certain technique of touching. You can't
just go like that [action] because your nail would
touch it and that doesn't work so you have to slide
off rather than...and I found that at home. But as I

eme 'speed' is also shared by the groups. It reflects the speed party were supposed to go, or did go. For instance:

r): " [R]: so did you find the test
: in the beginning. [C]: yeah with
edge to it. [L]: yeah I was a bit
wish we was being timed and we
now we done. I got really competi-

The sub-theme ‘tactic’ refers to the tactics both the older and younger groups had when completing the iPad test. For instance:

Tactic (younger): “[C]: yeah and also like how I went about it, like at the start I was just like looking 1, 2, 3, 4, as opposed to once I had an unhappy face it changed how I did it, like I was looking at groups so I would find 1, 2, then 3 and 4, then 5 and 6, and I found that I was quicker because it would take me an extra second to look but I tap quicker then because I already knew where the other one was. So I changed how I attended to it. [L]: changed your strategy. [C]: yeah”.

The final shared sub-theme is ‘performance feedback’ which relates to how much feedback they would ideally like to have had from performing the iPad test. For instance:

hter]. [P]: see you have got no I have to hit the keys with my podgy er]. [C]: yeah it was like 6 and 8 ked similar, that was the two that I rong. I went for an 8 instead of a 6 ok so similar, but I knew straight it wrong”.

eme ‘search strategy’ is unique to It reflects the strategies employed unger participants to perform the nce:

e it depends on how you attend to whether you’re a linear searcher a look at the holistic picture and ly sit back and look at the whole at point you’re more susceptible to s because I could just sit there with then if they were split between left nd it easier to go from one side of he other using two hands rather re grouped around one area”.

main aim of this study was to pro- p-based qualitative evaluation of gnitive test on a mobile device and eceptability with both younger and ularly related to the participant’s let technology. The potential influ- eedback and researcher presence ance was also examined.

numbers just in a different location. Yeah I found it boring towards the end. [R]: yes and that is perfectly fine, I want you to be as honest as you can. Thank you [G]”. The younger participants also expressed the test experience as positive, for instance, “[R]: fab, thank you. Did you enjoy doing the test? [A]: it makes me want one [iPad]. [P]: it was interesting but I wouldn’t use the word ‘enjoy’ [laughter] I was just counting dots but it was a little more engaging that some can be. However, others also deemed it to be ‘boring and distractible’, thus “[R]: ok, so would you say then something like that could be used on a regular basis or would you say no? [L]: I think it was boring”.

Feedback

In the MILO test, performance feedback was given in the form of an unhappy face icon when a mistake was made. However, we can see from the comments made in this study that in real life, rather than providing a potential learning opportunity, via feedback, such an icon can have a demoralizing effect, with evidence that an individual experiences embarrassment if an observer can see the unhappy faces, i.e., their poor performance. These factors may detrimentally affect test results and render the individual less likely to want to do the task again. Related to this was the finding that people could feel very self-conscious when being watched; again the presence or not of an observer may affect an individual’s test performance. A number of participants were embarrassed at the thought that the researcher present could see if they had an unhappy face pop up. Although this might not be of importance if the tests are self-administered, it is a pertinent consideration when administered by another individual.

feedback *per se* and how it is perceived in terms of performance. It is certainly the case that the participants in our focus groups definitely had strong views about this issue.

What one would best engage with the test was also a divisive issue. Some said they would engage more attentively early in the morning, others later in the day. Using this test in a clinical setting would need to take into account the test users' preferences for time of day and the actual time of day. Real-world situational circumstances where the test is used regularly as a cognitive tool, they would be advised to use it at a consistent time of day and the times tests were used if the impact was severe.

Associated instructions

In this study we have highlighted several factors that are relevant to the development of tablet or computer-based tests of attention and reaction time tests used in the assessment of cognitive function.

There may introduce bias, variability and inconsistency in outcome is the reported heterogeneity of strategy, e.g., the use of one or two hands. It is important therefore that highly specific instructions are given to the participant (e.g., speed and accuracy) and that the individual's choice and execution of strategy is recorded. This is also a factor to consider if the same test is repeated, i.e., does

not make clear. For instance, the level of education about the systems purpose, i.e., is it the speed or the accuracy of their performance which is most important? There was much disparity regarding what the participants thought was most important despite clear instructions given prior to the start of the test. Their lack of clarity could have been due to their preoccupation with the testing situation. If so, then it should be made a priority that they fully engage with the instruction process prior to the start of the test. The inclusion of a practice trial could be implemented in the future.

These issues seem to suggest that participants might have treated the test more like it was a video game as opposed to a cognitive test with an approach that involves strategizing to maximize the score they receive and possibly an increased sense of motivation or competitiveness with other players to get a "high score". Researchers have not examined the attitudes and motivations of people who engage with cognitive testing, however, the motivations for video game play are quite well understood. Engagement with video games can be intrinsically motivating with reward derived from simple actions and immersion in game [39] or motivation can be derived from a sense of challenge or competition in the game and the accomplishment that come with it [40]. In conventional video games, these motivators can drive people to practice/play more and become extremely skilled with the games, improving their scores and their visuospatial awareness [41]. The questions this raises for the digital tests are first, whether the test motivates practice in the same way a game does, and second, whether this practice invalidates the test. For example, if one becomes too practiced, then test-performance ceiling effects can be induced.

y in the room could also interfere
see the stimuli. Again, the tilting
stand could assist in reducing the
t also the researcher should take
nt when selecting an appropriate

iving long finger nails physically
rs and affected their responses as
ngers, and having arthritis in their
ngers (see above). Some of the par-
the use of a pen/pointer instead of
conductance of their fingers. This
te the need for too much empha-
hands or fingers should be used,
se the pen/pointer. This indicates
considering when developing such
dexterity and concurrent illnesses
physical ability to respond appro-
allowances need to be put in place
chers and clinicians to control for
affecting their results.

allenges reported above are consis-
n Weilenmann [42] in the context
le phones. The senior informants
d text on the mobile phone, which
al pressing of keys within certain
ipants reported issues regarding
hythm of key-pressing: (1) Doing
pressing was not a straightforward
ed to press too slowly or pressing
of time than the other, (3) slow
nd movements.

been argued that touch-displays
e intuitive to use for older adults
robust evidence in the HCI litera-
is commonly believed argument

that elderly people with dry or wrinkled fingertips
had a significantly higher touch recognition error rate
on some tablets. This could also be related with the
layer types of the resistive touch-screen technology.
Harada et al.'s [46] study also support dry-finger and
users' frustrations with unresponsive taps.

CONCLUSION

Arguably iPad-based tests may be an ideal base for
home testing, with subsequent increased compliance
in clinical trials, longitudinal clinical and research
follow up, and the ability to signal deterioration and
thus to facilitate intervention, but many factors need
to be considered in their development if such tests are
to be reliable, valid, and objective. The participants in
this study highlighted several issues pertinent to the
development of tablet or mobile-based tests typical
of those used in the assessment of cognitive func-
tion in older adults, which can then be used to inform
more specific development for testing in individuals
with cognitive impairment and dementia. In order to
inform those considering developing tasks of RT and
other aspects of cognitive function on touch screen
based tablets, we summarize the information gained
from our focus groups in the following section in a
series of bullet points. It is clear from this informa-
tion that many factors, which may not be currently
taken into account when designing such tasks for
use on touch screen tablets, but which, without being
addressed could significantly influence task perfor-
mance and thus adversely affect the clinical validity
of such a test.

- Without highly specific instructions, response
strategy to test components and stimuli can vary
between individuals, despite clear instructions given

tely. As such, allowances need to be made in order for researchers and clinicians to account for changes in physical ability

Participants treated the test more like a videogame than a cognitive test and thus used a more relaxed approach that involves strategies to achieve a high score, and possibly an increased sense of achievement or competitiveness with other participants (one of the focus group) to get a “high score.” This is related to videogame play is well understood. For example, engagement with a videogame can be intrinsically motivating with simple actions and immersion. Motivation can be derived from a sense of achievement or competition in the game and the challenges that come with it [40]. In conventional testing, these motivators can drive people to practice more and become extremely skilled, thus improving their scores and their visual acuity [41]. The questions this raises for cognitive tests are whether the practice in the same way a game does (e.g., similarity with a given game or the use of a commonly used for gaming) and whether this practice invalidates the test. If one becomes too practiced then ceiling effects can be induced, or practice may help to improve or stabilize performance with cognitive decline.

In the MILO test, performance feedback was given in the form of an unhappy face icon when a low score was made. However, we see from the results in this study that in real life, a low score is a potential learning opportunity.

- Physical challenges that affected test performance included the wearing of glasses (e.g., slipping down their nose when their head was bent over the tablet which was positioned flat upon a table), particularly with varifocals. Therefore, the ergonomics of the tablet positioning in relation to the required use of visual aids is of great importance when developing such tests, see also [42]. A suggestion from some of the participants was that the tablet should be placed in a tilted stand, and indeed spontaneous tried to hold it in this position so they could see the stimuli. However, although this position may ameliorate some physical difficulties, it is possible that it may affect performance in other ways as yet investigated and thus once again consistency of positioning would be highly important. The positioning of the tablet in relation to lighting in the room can also interfere with the ability to see the stimuli, thus lighting becomes an important consideration when selecting the testing environment.

There are of course limitations with our focus group study. For example, individuals living with dementia or cognitive impairment were not included, and it is possible that test administration, reaction to it, and performance varies with the integrity of cognitive function. Future studies should include a wider range of tests and their validation with other forms of computerized testing, groups representative of a wider range of age-related changes such as those found in relation to vision (such as cataracts, wearing glasses, color blindness), hearing, mobility and dexterity, memory function (what happens if individuals forget the instructions?), and levels of motivation and response confidence (e.g., examining the potential for guessing the response). Other pertinent factors for developers to consider in the future

tion, whether individuals always use the same response strategy throughout the test or whether different people use different strategies. Considerations regarding the optimal device and performance such as fixed viewing distance, device size, individuals may move the iPad closer or further away to compensate for changes in their visual acuity, the angle of the iPad during stimulation (at an angle or flat on a table), ambient noise, and lighting, technical aspects such as device and operating systems [11], the feasibility of using the internet to access the test or to deliver the test [9], how used to using the internet is the person [9], how to ensure the reliability of the person taking the test, the intrinsic design of the iPad can be considered [11]. Finally, it is important to consider whether a test to be included in routine clinical practice, the needs of different user groups (e.g., patient, clinicians, scientists, developers) need to be investigated and compared with the development stage of such tests with the development of quality criteria for the tests. The results of this small study lead to the consideration of such factors relevant to tablet-based tests of cognitive function. Future work will need to focus on better understanding the impact of physical challenges to cognitive performance, technical familiarity as the number of users who regularly engage with such

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